

Graduate Certificate in Antarctic Studies

Individual Research Project

Hydroponic Food Production at Scott Base



Due 16th February 2007

Preface

Originally, this study was intended to review material that Antarctica New Zealand held concerning its abandoned hydroponics system. After the review, suggestions were to be made on implementations that could overcome the problems experienced in the previous system. However, with evident lethargy and lack of interest Antarctica New Zealand failed to provide any substantive information regarding the previous operation, despite their agreement to do so. For this reason, the following report is largely a review of hydroponic gardening. There is some attempt to relate this to the Antarctic and similar application.

Summary

During the winter period staff operating Antarctic bases are cut off from the outside world. These remaining staff must survive on provisions from the previous season, fresh vegetables, herbs and fruit are non-existent on the base. Hydroponic facilities operating under controlled conditions, with artificial lighting can provide the highly valued fresh produce for winter residents.

The design of controlled climate hydroponics must cater for all of the plants growth and development requirements in the same way that nature does in lower latitudes. These requirements are far removed from the Antarctic environment, and replicating them can be both energy and labour intensive. This report compares different hydroponic options and looks at what plants need in controlled climate agriculture in order to provide a productive facility.

There is then a brief assessment of how the facility at Scott Base (of which there is very little information available) could be improved with energy efficient lighting. The lighting system suggested is LED horticultural lighting. The application of LED lighting to horticulture is a new field and as a result, the technology is costly. The high setup cost of this type of lighting would likely deter Antarctica New Zealand from pursuing this any further. The reuse of treated wastewater within the hydroponics facility is also considered. However, in the absence on any information confirming the high standard of wastewater treatment claimed by Antarctica New Zealand no recommendations are made to utilise this resource.

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1 Introduction

During southern hemisphere winters the transportation of supplies to Antarctica stops for eight to nine months. Historically during this period, residents of Scott Base have relied on non-perishable food items for their total sustenance. During the mid 1980's the Department of Scientific and Industrial Research (DSIR) invested in a pilot study to investigate producing small amounts of fresh vegetables at Scott Base using hydroponics (Janata, Varcoe, and McDonald 1986).

The present Scott Base hydroponic greenhouse was constructed and commissioned in the winter of 2000 and consists of 2 x 20 foot shipping containers mounted beside the main powerhouse to take advantage of the waste heat. It has operated continuously since its commission except for period of a few weeks at the end of 2002 summer season. Produce ranges from herbs and flowers, tomatoes, snow peas, cucumbers, zucchini, lettuce, capsicum, chilli peppers, to strawberries, squash, spinach & swiss chard (Rich 2003).

Hydroponics is a term applied to the cultivation of plants in nutrient solutions without the use of soil. It began in the 1930's as an outgrowth of the techniques used by plant physiologists in plant nutrition experiments. Current hydroponic growth methods differ in particulars but have two common features: (1) nutrients are supplied in liquid solutions; and (2) plants are supported by porous materials, such as peat, sand or gravel, that act as a wick to relay nutrient solution to the roots. The DSIR and later Antarctica New Zealand (AntaNZ) have maintained hydroponics systems at Scott Base until final closure of the facility in 2004, voicing energy and bio security concerns.

2 Hydroponics General

The term hydroponics originally meant nutrient solution culture with no supporting medium. However, plants growing in solid media for support, but using nutrient solution are also included in hydroponics. This technique is called aggregate system. Hydroponics systems are further categorized as open (i.e., once the nutrient solution is delivered to the plant roots, it is not reused) or closed (i.e., surplus solution is recovered, replenished and recycled)(NASA 2006). Hydroponic facilities exist around the world in all climates for growing both vegetables and flowers (Resh 2002). In arid regions of the world such as the Middle East, hydroponic units are combined with desalination plants to use seawater as a source of fresh water. In the former USSR large hydroponics greenhouses are used to grow crops in the extreme climates of Moscow and Kiev (Resh 2002).

2.1 Hydroponics in Space

Hydroponic food production is also seen as the future of space travel, with long duration space flights and colonies producing thier own food from energy, nutrients and water (NASA 2006). In the near future space farms will most likely be constrained to supplementing the dietary requirements of crews during short-term missions. Spacecraft like the International Space Station offer limited volume, mass and power for farming. Small payload launch masses of current heavy lift vehicles and an inefficient power supply by arrays of solar cells impose spartan resources for food production (Monje et al. 2003). In the distant future planetary bases are envisioned as being composed of large modules where larger growing areas and potentially larger power budgets could be available. In this case, more conventional controlled environment farming of staple crops (wheat, soybean, potato, sweet potato and rice) could be sustained, provided there is adequate lighting from either direct solar light, or electric lighting systems (Monje et al. 2003).

2.2 Antarctic Hydroponics

Currently the UASP operates hydroponic growing systems at both McMurdo and South Pole Station. The University of Arizona is working on the new South Pole Food Growth Chamber (FGC) Project, a self-contained greenhouse designed to grow food for Antarctic researchers during the winter season. The 300-square-foot Food Growth Chamber can yield fresh vegetables at a rate of 10,000 heads of lettuce a year (Morlocki and Citizen 2003). The size of the South Pole Growth chamber is comparable to Scott Base's 298-square-foot hydroponic space. University of Arizona's Controlled Environment Agriculture Centre has designed the state of the art facility at South Pole station. Much of the research work that has gone into the facility may one day have an impact on space travel.

"We are interested in the South Pole because we are interested in going to Mars," said Gene Giacomelli, director of the University of Arizona's controlled environment laboratory. Growing plants could be an integral part of any mission to the Red Planet, and no other environment on Earth resembles Mars more than the South Pole. Mars might even be more hospitable. Astronauts on spacecraft heading out on the months-long flight to Mars could have to rely on similar greenhouses for fresh food. "What they can't take with them, they will have to grow," Giacomelli said (Morlocki and Citizen 2003).

The design criteria state that the new South Pole Station requires a Food Growth Chamber that will provide an appropriate level of advanced technology, which a volunteer staff can operate. The purpose for including the FGC is to enhance the diet of the station personnel, as well as to provide for their visual and sensory needs for seeing, feeling, and interacting with plants (Giacomelli 2002). Researchers living there usually eat packaged food year round indoors. They can suffer from seasonal affective disorder (SAD), a health malaise brought on by a lack of full spectrum natural light, and they long for the sight, taste and touch of plant life in the most isolated place on earth. Researchers have also learned that having access to plants can raise morale and increase productivity (McGinley 2002). The ultimate goal of the Food Growth Chamber is to

provide a better quality of life for researchers who live and work at the South Pole, and to help others understand how people can adapt to living in seclusion without seeing the sun for months on end (McGinley 2002).

In contrast to the high-tech, state of the art facility installed at South Pole station, the greenhouse at McMurdo Station was built mainly by volunteer labour. The original structure has been expanded to its current size of 649 square feet and can generate a monthly average of 275 lbs of produce. The technology within the McMurdo greenhouse is comparable with that of the Scott Base facility. Produce from McMurdo greenhouse includes lettuce greens, spinach, chard, tomatoes, peppers, cucumbers, sprouts and herbs. The harvest is ample enough to provide a winter community of up to 230 people a salad once every 4 days, plus many fresh herbs, veggies, and fruit for the galley chefs to incorporate into their menus (Rich 2003). Limited information is available on the current hydroponics set up, the system is housed within two twenty foot shipping containers, giving a total area of around 298 square feet (ADDIS 2007). The overall system consists of three tank and pump units, two of which are NFT systems and operate continuously. The other tank is an ebb and flow system, and pumps twice daily to flood two reservoirs (Rich 2003).

2.3 Water Vs Soil Culture

The major attraction to hydroponics for commercial operators is the increase in crop yield over that of conventional soil culture. The increased yield in hydroponics is attributable to two factors. Firstly, soils in some cases may be lacking or highly variable in nutrients, while in hydroponics the nutrient solution is tightly controlled and easily adjusted to provide the optimum conditions for growth. Secondly, the presence of pests and disease in the soils will often greatly reduce the overall productivity of soil-based culture. Hydroponic systems are usually isolated from the natural environment, preventing pest and disease vectors entering the crops. Other benefits of hydroponic production include increased crop density; more plants can be “planted” on the same area as the limiting factor becomes light availability not nutrient supply. The absence of weeds also reduces the labour required to maintain hydroponic crops and removes resource competition from the crop plants.

3 Types of Hydroponic Systems

Many different hydroponic systems exist, some of which combine aspects of different systems to create hybrids; however, there are three main styles of hydroponic systems.

3.1 Floating Hydroponics

This type of system uses large tanks or shallow ponds of nutrient solution with floating planted rafts of lightweight material such as polystyrene. The plant roots hang below the floating raft in the nutrient solution and no growing aggregate medium is required. This systems main advantage is in large-scale production, where the nutrient solution pond can be created as a long channel. This long channel then acts as a conveyor, with seedlings at one end and harvestable plants at the other (Morgan 1999). The floating hydroponics system is shown in figure 1.

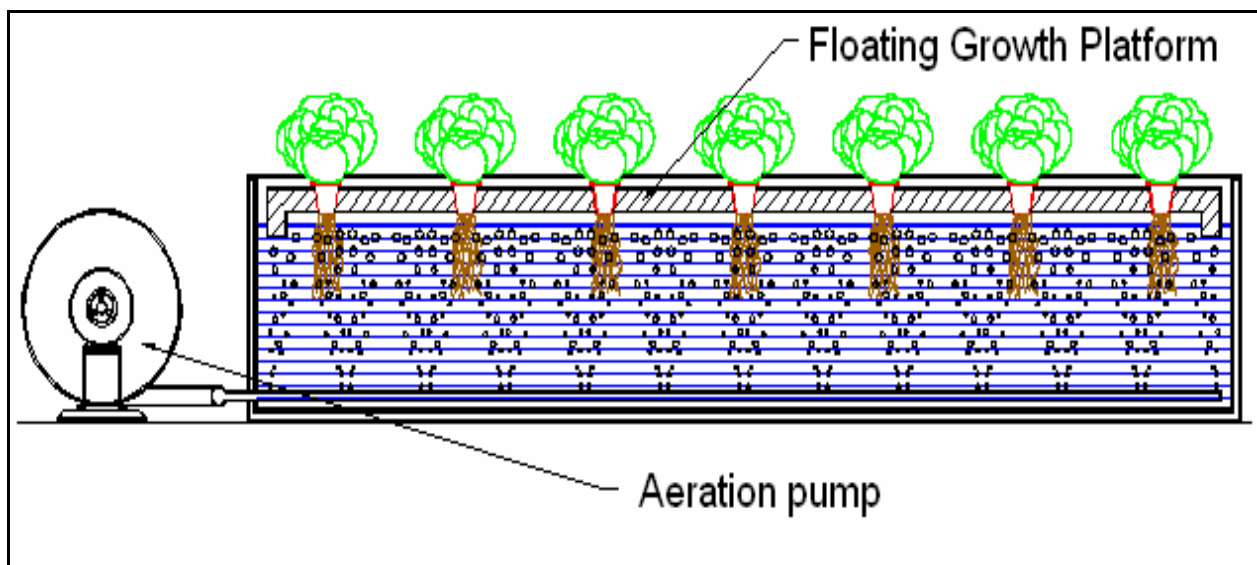


Figure 1; Floating hydroponics system.

3.2 Nutrient Film Technique

The nutrient film technique (NFT) gets its name from the thin “film” of nutrient solution that flows through plastic channels containing the plant roots. There is no solid planting media used with this technique. The root mat develops partly in the shallow stream of nutrient solution and partly above it. Because the root is only in contact with a flowing film of nutrient solution, adequate oxygen access is available to the root (Morgan 1999). The NFT set up is shown in figure 2.

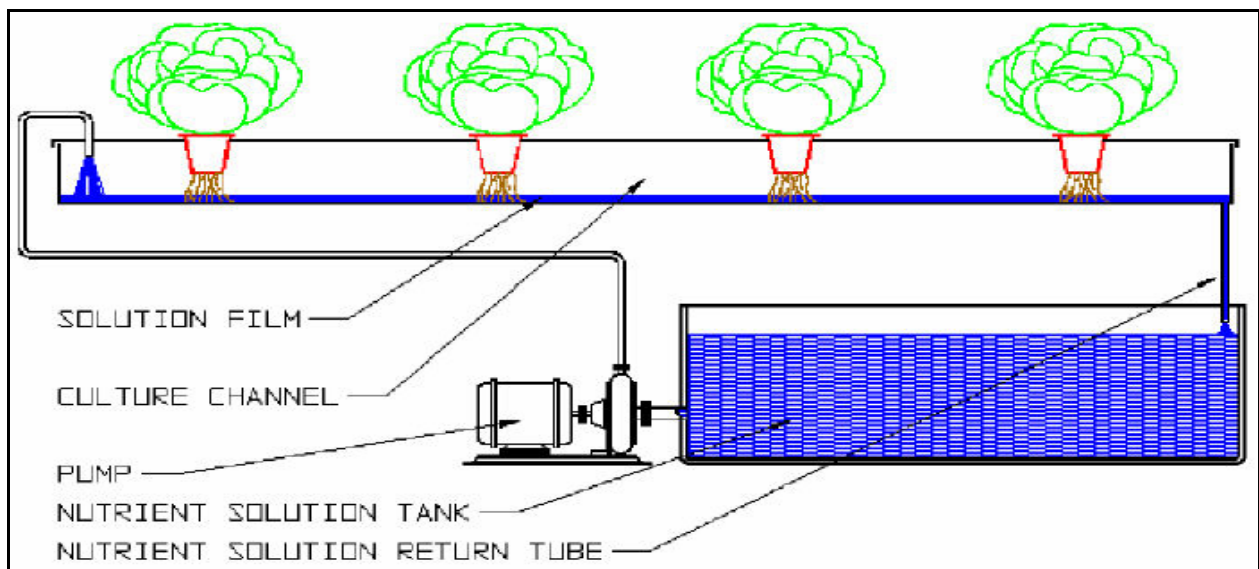


Figure 2 Nutrient film technique hydroponic system.

The key requirements of the NFT system are:

- A uniform flow of nutrient solution down the channel
- Low inlet flow rate to ensure that the nutrient film remains shallow in channel
- Wide flat channel to ensure root mat does not block nutrient solution, and an even flow depth is achieved

3.3 Ebb and Flow Hydroponic

Here a reservoir containing nutrient solution is located below a growing tray. The tray contains the plants that are in a growing medium. The growing medium in which the plant roots are located needs to have high water holding capacity. Material such as crushed rock has a low water holding capacity, therefore needs frequent watering, while materials like vermiculite or perlite have high water holding capacity, and require less frequent watering. When the crop is watered, a small pump on a timer switches on and floods the growing tray. The timer then shuts the pump off and the nutrient solution drains freely back into the reservoir drawing oxygen into the root zone. Ebb and Flow systems' are favoured because of their low maintenance, high productivity, and ease of use (Morgan 1999). Figure 3 shows the ebb and flow setup.

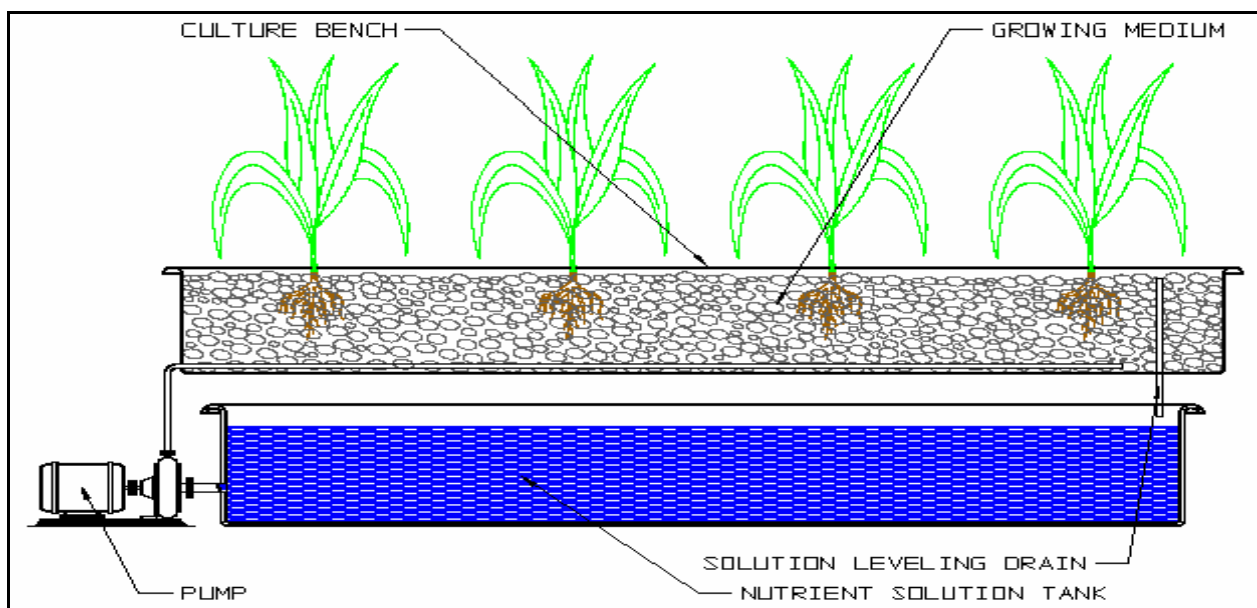


Figure 3 Ebb and flow hydroponics system.

4 Plant Nutrition

In hydroponics the essential elements that are required for plant growth are supplied to the plant in the form of dissolved fertilizer salts (Resh 2002). Assuming that the nutrient solution contains all the essential elements for plant growth and that they are all in the correct proportions, only the concentration of the nutrient solution need be adjusted to optimise plant growth. If the concentration is too low, growth will be slow and the resilience of the plants will be reduced. If the concentration is too high the plant leaves will grow rapidly, but the tips will begin to burn, go brown and die (Romer 1997). In many plants, high nutrient concentrations will reduce the movement of water within the plant, which reduces the process of respiration and limits the overall growth of the plant. For fruiting varieties, a low nutrient concentration will result in watery tasteless fruit, while high nutrient concentrations may cause bitter fruits owing to the sugar / salts ratio being out of proportion (Romer 1997).

The solubility of fertilizer is a measure of the concentration of the salt that will remain in solution when dissolved in water. Only highly soluble fertilizers salts can be used in hydroponics systems, as the nutrients must remain in solution in order to be available to the plants. The solubility of nutrients with the fertilizer is also related to the pH of the solution, this is addressed in a subsequent section.

Many different hydroponic nutrient formulations have been published and premixed hydroponic fertilizers are sold. These premixed nutrient formulations are all similar in their constituents, differing mainly in the ratio of nitrogen (N) to potassium (K) (Romer 1997). In general, leafy crops such as lettuce and spinach require more nitrogen than fruiting crops like tomatoes and strawberries, which require more potassium for fruit growth and quality (Morgan 1999). Unless growing on a large scale it is uneconomical to produce your own fertilizer blend. Premixed fertilisers will contain all the elements needed for a specific crop; therefore growing multiple crops will require different nutrient solutions (concentrations and constituents) and separate plumbing circuits.

4.1 Major Nutrients

The major essential elements required within nutrient solutions for plant growth, and their contribution to the growth process is as follows:

Oxygen

Important element in the process of respiration, plants obtain oxygen from two sources. Firstly, plants absorb oxygen from the atmosphere through stomata in their leaves, but uptake through the roots is important. In hydroponic systems, the uptake of oxygen through the root system can fail if the nutrient solution is not aerated sufficiently (Ross 1998).

Hydrogen

Plants obtain most of their hydrogen requirements from water absorbed through the roots. Hydrogen is a vital component in the chemically reduced fats and carbohydrates (along with carbon and oxygen) produced by photosynthesis (Ross 1998).

Nitrogen

Plants require nitrogen for the production of proteins, chlorophyll, protoplasm, hormones and some acids. If a plant receives too much nitrogen its growth may be soft and spindly, if it receives too little growth may become hard and slowed. Most plants receive nitrogen via the root system from the soil or nutrient solution; however, some plants such as legumes can fix nitrogen from the atmosphere (Ross 1998).

Phosphorus

Phosphorus is particularly important for fruiting plants. It stimulates the production of flowers and fruit, encourages healthy root growth and expedites the process of ripening. Plants receive phosphorus via the roots from the soil or nutrient solution (Ross 1998).

Potassium

Particularly important in fruiting plants, potassium affects the flavour and storability of fruit crops. Excess concentrations may cause a reduction in magnesium uptake by the plant (Ross 1998). Plants receive potassium from the soil or nutrient solution via the root system.

Magnesium

Magnesium is important in the production of chlorophyll. If a plant is deficient in magnesium, it will transfer magnesium from older leaves to newer leaves. This reduces the chlorophyll in the older leaves, which become yellow and brittle, reducing the overall efficiency of plant photosynthesis (Ross 1998). Plants receive magnesium from the soil or nutrient solution via the root system.

Sulphur

Supplied to the plant from soil or nutrient solution, sulphur is incorporated into a number of organic compounds such as proteins and amino acids (Ross 1998; Sutcliffe and Baker 1974).

Iron

Required for the production of chlorophyll, a deficiency will often cause a lack of chlorophyll in new leaves. This will show up as a yellowing of new growth, this will slow the development of the plant (Ross 1998; Resh 2002).

Manganese

Activates enzymes that are responsible for DNA and RNA formation. May also have the same affect as iron on chlorophyll production but not limited to new growth (Resh 2002; Ross 1998).

Calcium

An essential part of plant cell wall structure, provides for normal transport and retention of other elements as well as strength in the plant. It is also thought to counteract the effect of alkali salts and organic acids within a plant. Plants receive calcium from nutrient solution or soil via the root system (Sutcliffe and Baker 1974).

4.2 Micronutrients

Micronutrients are required in very small amounts to support plant growth. The most common micronutrients required in nutrient solutions are as follows:

Boron

Helps in the use of nutrients and regulates other nutrients. Aids in the production of sugar and carbohydrates, also essential for seed and fruit development (Resh 2002).

Copper

Important for plant reproductive growth. Aids in root metabolism and helps in the utilization of proteins.

Chloride

Aids plant metabolism, acts as an enzyme activator during the production of oxygen from water (Resh 2002).

Molybdenum

Helps in the use of nitrogen; acts as an electron carrier for the conversion of nitrate to ammonium as well as helping nitrogen fixation (Resh 2002).

Zinc

Essential for the transformation of carbohydrates, regulates consumption of sugars. Part of the enzyme systems that regulate plant growth (Resh 2002; Ross 1998).

4.3 pH and Nutrient Availability

The term pH (potential of Hydrogen) is a measure (on the logarithmic scale) of the availability hydrogen ions in a solution. Generally, the range of 6.5 to 7.5 is considered circum-neutral, with a zero being acid, and fourteen being alkaline. The pH of a hydroponic nutrient solution influences the availability of nutrients to the plant, some nutrients are more soluble at low pH (acid) and others at high (alkaline). The relative solubility of plant nutrients are shown in figure 4. Below about pH 5.5 the availability of phosphorus, potassium, calcium, magnesium and molybdenum decline, whilst above pH 6.5 iron and manganese are not readily available (Ross 1998). In order to provide optimum nutrients to plants the pH of the nutrient solution should be maintained around 6.3 to 6.5 (in general) (Resh 2002), 5.5 to 6.5 (tomatoes) (Ross 1998), 5.6 to 6.0 (lettuce)(Morgan 1999). The pH of the nutrient solution needs to be checked on a regular basis, adjustments are made with the addition of calcium carbonate (CaCO_3) to reduce acidity and nitric acid (HNO_3), phosphoric acid (H_3PO_4) or similar to increase the acidity (Resh 2002).

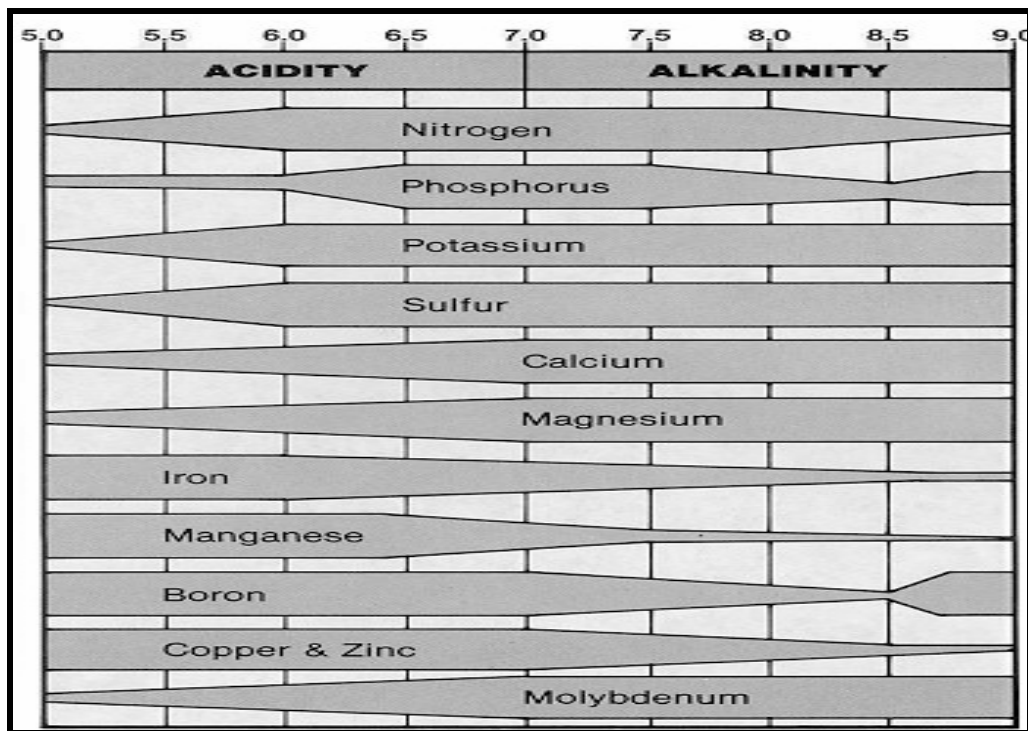


Figure 4: Nutrient availability in hydroponic solution (no vertical scale).

5 Conditions for Hydroponic Plant Growth

All living organisms live and thrive within a given climate range, these favourable conditions will vary for each species (Janata, Varcoe, and McDonald 1986). When controlling the local climate for indoor agriculture conditions must be replicated that favour all of the species that are intended to grow. However sometimes, short deviations from the comfortable conditions for plant growth will increase the yield from the plant. This is the case for some fruiting crops such as strawberries, which will show improved fruit yield if cooled for a short period then returned to their optimum comfort range (Janata, Varcoe, and McDonald 1986). For indoor hydroponics, the conditions that must be controlled to stimulate plant growth are ambient temperature, solution temperature, humidity and light.

5.1 Ambient Temperature

Typically, the ambient temperature of a controlled growth environment is maintained at between 12 degrees and 30 degrees Celsius. Short-term deviation from this temperature band can be tolerated by most vegetable and herb plants down to 5 degrees and up to 40 degrees, but these temperatures will induce a dormant state in the plants, which will reduce growth rates for several days (Janata, Varcoe, and McDonald 1986).

5.2 Solution Temperature

Adjusting the temperature of the nutrient solution allows an efficient way of heating or cooling the plant roots, and may heat the surrounding air. Winter grown crops benefit from heated nutrient solution, especially when the plants are small and closer to the source of warmth (Morgan 1999). Generally, best results are achieved if the nutrient solutions (and therefore plant roots) are kept between 18 and 28 degrees Celsius.

5.3 Humidity

As temperatures increase, air can hold more water and relative humidity goes down, although the amount of water on an absolute basis may be the same. The difference between the amount of water in the air at a given temperature and the amount it can hold at that temperature is the vapour pressure deficit. At low vapour pressure deficits, transpiration may be too low, while at high vapour pressure deficits, transpiration may be excessive. The amount of water that a plant transpires must be replaced through irrigation. In the controlled environment of a sealed hydroponics greenhouse, there is a finite space for the transpired water to occupy, so the humidity may increase quickly if the temperature is high. Humidity can stress plants if it is either too high or too low. High humidity may cause fungal disease, while low humidity may inhibit flower development and pollination.

5.4 Light

Light is an environmental factor that is uniquely involved in programming rhythmic processes which regulate the orientation in time of both plants and animals (Hart 1988). Plants utilise light directly in biomass production through photosynthesis. Photosynthesis is a complex set of reactions which require both light and dark periods. During photosynthesis the green pigment chlorophyll which gives a plant its green colour, absorbs light and working with carbon dioxide and water produces sugars.

The process that takes place during periods of light is a photochemical reaction, the process that occurs during the period of dark is an enzyme reaction (Ross 1998). The plant requires a period of dark in order to complete the conversion of carbon dioxide, water and sugars, and to facilitate the release of oxygen. The extent to which photosynthesis reactions occur depends on both the quality and the intensity of the radiant light energy received by the plant.

The sun is by far the most important source of biologically significant natural radiant energy. In controlled climate agriculture, the energy-providing role of the sun is

replicated with artificial light energy. The sun emits a continuous spectrum of radiant energy, but only radiant energy between 300 and 1000 nm influence life processes. Radiant energy that occurs between 300 and 1000 nm is referred to as the “biological window” (Hart 1988). Sunlight on the earth’s surface during summer at noon is generally around 1000 watts per square meter. The process of photosynthesis is saturated at between 200 and 300 watts per square meter, and germination of seeds typically occurs around 100 watts per square meter (Hart 1988).

Photosynthesis is better predicted by counting photons within radiation rather than using watts per square meter as a measurement of incoming energy. The measure of photons per meter squared per second is called an "Einstein", this is the measurable unit of irradiance. A whole Einstein is defined as 1 mole of photons. The unit used for photosynthetically available radiation (PAR) irradiance is a millionth of an Einstein per square-meter per second, or 6.02×10^{17} photons per square-meter per second, the microEinstein (μE).

But while the microEinstein is a much better way to estimate a lamp's plant growing ability, it is still very difficult to directly compare two different types of plant lights. Most plant lights emit large amounts of light that plants don't use very efficiently, so including that light output in a light's plant growing measurement is misleading (Cardinale 2007).

Full sunlight on a clear summers day around noon is approximately 2000 μE . Plants do not use much of this energy, as the light is too intense (Turnbull 2007). Typically, the photosynthetic capacity of the plant (ability to use light) is saturated at around 500 μE . For example, plant growth cabinets at the University of Canterbury operate at around 600 μE , this intensity ensures complete light saturation of subject plants (Turnbull 2007). Although the intensity of light received by plants may be saturated at 500 μE much of this light is not PAR, so only a fraction of this light is directly used in photosynthesis (Cardinale 2007).

Conventional controlled climate agriculture has used three different types of artificial light to provide growing energy to plants. These light sources are fluorescent lights, High Pressure Sodium (HPS) lights and Metal Halide (MH) lights. HPS and MH lights are sometimes referred to as high intensity discharge (HID) lights. The two major problems with the HID lights are the heat that they generate and the power that they consume. Typically, the surface temperature of the bulb will be in the range of 400 – 1000 degrees Celsius. In an enclosed space such as a greenhouse, these high surface temperatures soon increase the ambient temperatures of the growing space. Most HID bulbs are a minimum of 400 Watts, with each bulb providing sufficient light for only a few square meters of growing space. Therefore, large areas will require many bulbs and a lot of electrical power to run. With all artificial lights, the light intensity is greatest near the bulb and diminishes with the square of the distance as you move away. Thus, a light that gives 1000 lumens 1 meter away will give only 250 lumens at 2 meters. Fluorescent lights use less power but do not provide the same intensity as the HID lights. Because of the lower intensity of fluorescent lights they need to be closer to the plants, this limits their usefulness to low profile plants such as lettuce and seedlings. It is difficult to grow high profile plants like peppers or tomatoes under fluorescent lights.

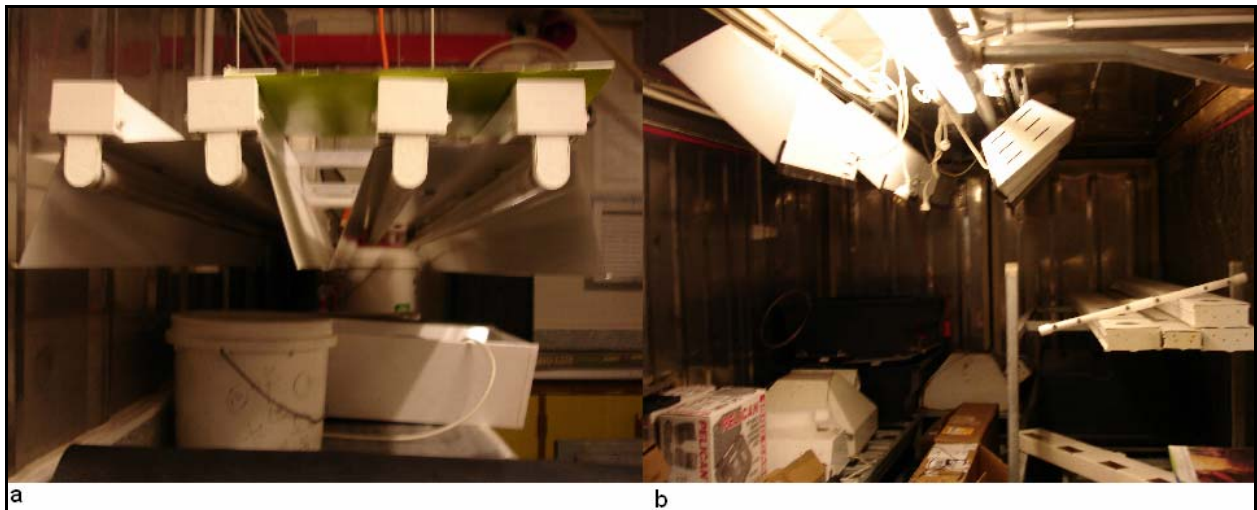


Figure 5 Different lighting systems at Scott Base a) fluorescing lighting b) high intensity discharge lighting.

6 Hydroponics at Scott Base

The existing abandoned hydroponic system at Scott Base consists of three tank and pump units, two of which are NFT systems and operate continuously. The other tank is an ebb and flow system, and pumps twice daily to flood two reservoirs. The engineering staff maintain the system and daily monitoring and running of the unit is undertaken by the domestic/kitchen staff (Rich 2003). Due to impromptu construction and lack of record keeping at Antarctica New Zealand no further technical information is available to elaborate on this description.

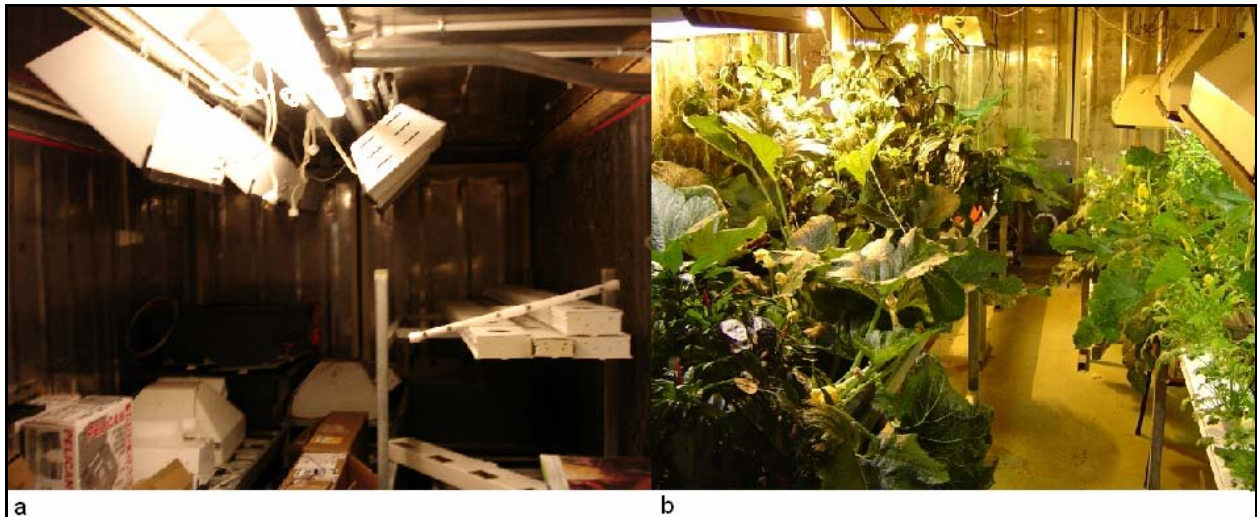


Figure 6: Changing roles, a) current condition of hydroponics area at Scott Base, b) system in operation (pre 2003 – 2004).

6.1 Closure of Scott Base Hydroponics

In 2002, springtails were discovered in the water in the hydroponics unit. The cause of this invasion is not known. The substrate the plants grow in was sterile vermiculite, water used in the unit was clean reverse osmosis treated water. Plants in the system were grown from seed and no living plants or seedlings were imported to the unit (Huston 2007). With these procedures in place, the vectors for the contamination seem limited. Possible mechanisms of introduction include; transfer in seed packets, cross contamination from other base activities e.g. kitchen greens, importation from McMurdo hydroponics unit while exchanging cuttings or sharing equipment (Huston 2007).

Samples of the invading species were collected and analysed, these were identified as springtails of the family *Isotomidae* (possibly a *Folsomia* sp.). Springtails are tiny wingless insects with distinctive heads and a hump-backed appearance. Their name comes from a forked structure attached to the underside of the abdomen that acts a spring to flip them into the air. This behaviour gives them the appearance of tiny fleas. Other than being a nuisance, these unique little creatures pose no threat (Townsend 1994). Plants grown in greenhouses sometimes become infested because of heavy breeding in the moist conditions. Allowing the soil to dry out will usually eliminate them. Some species, such as the garden springtail can be found on field crops and vegetables, but they rarely cause enough damage to warrant control measures (Townsend 1994).

The hydroponics unit was dried out, all material removed (treated as food waste), and the system cleaned with bleach. The temperature in the unit was rapidly dropped once cleaning was completed, to further reduce the possibility of survival. Once no further signs of springtails were visible, the unit was re-established and plants, vermiculite and water checked weekly for any signs of re-colonisation. Two years later, the hydroponics facility was again infested with the springtails, this time the facility was cleaned out and not re-established due to high energy consumption and bio-security concerns (Huston 2007). The hydroponic facility has remained dormant until this time where it is currently used as an informal storage area.

7 Energy Efficiency

Scott Base is powered by 2 main generators with a back-up generator system to ensure constant power. The generators supply heat and light to the eight main interconnected buildings comprising Scott Base. These buildings have a combined floor area of 2340 sq m of which 570 sq m is used for accommodation (Antarctica_New_Zealand 2007). The cost of energy production at the base is estimated to be 23.00 cents per kWh (Brookman 2007). This cost is not as high as may be expected, when compared to Auckland city residential rates of 18.92 cents per kWh (Meridian Energy 2007). The increased energy cost in Antarctica is associated with the transport of fuel and operation and maintenance of generators. However, without the assistance of the USAP, New Zealand's fuel costs would be considerably higher for Antarctic operations. Increasing the energy efficiency of New Zealand's operations in Antarctica is as much of environmental concern as it is an economic constraint. As a government organisation with a growing environmental focus, reducing fossil fuel usage is of primary concern.

7.1 Lighting

Recent advances in semiconductor technology have led to development of light emitting diodes (LEDs) capable of high irradiance with electrical efficiencies at least equivalent to other lamps currently used as plant light sources. The LED has other characteristics, such as safety, reliability, long life, and low mass and volume, making it a very desirable irradiance source for space applications (Quantum_Devices_Inc. 2007).

Emitting 100% Plant-Absorbed-Light, LED horticultural light arrays produce only colours of light that plants need to grow. High-wattage HID lighting systems produce only 25% visible light, the rest is invisible heat, and only $\frac{1}{2}$ an HID's visible light is actually absorbed by plants and used for photosynthesis (LED_Growmaster_Global 2007). LED horticultural lighting systems use a combination of coloured LED bulbs to provide the specific light colour and wavelength to encourage plant growth. The power usage of the LED lighting is only a fraction of HID bulbs, making them particularly attractive for situations where energy supply is limited.

The remainder of this section is largely based on sales information provided by a commercial company in the United States, LED Growmaster Global Inc. The product that Growmaster Global market is an array of LED bulbs, the array combines specific colours and wavelengths to maximise plant growth. The combination of LED bulbs has been patented (US patent No 6, 921, 182) for horticultural applications, and other aspects of the design are patent pending. Information that has been provided by Growmaster Global has been voluntary; parts of this information are reproduced in this report. This section should be considered as a suggested utilisation of the Growmaster Global product, not as an original design.

The LED grow bar produced by Growmaster Global incorporates a series of Led arrays in a single lighting unit. The unit pictured in figure 7 has five arrays, this is the largest grow bar produced currently. This unit draws around 9 watts of electrical power.

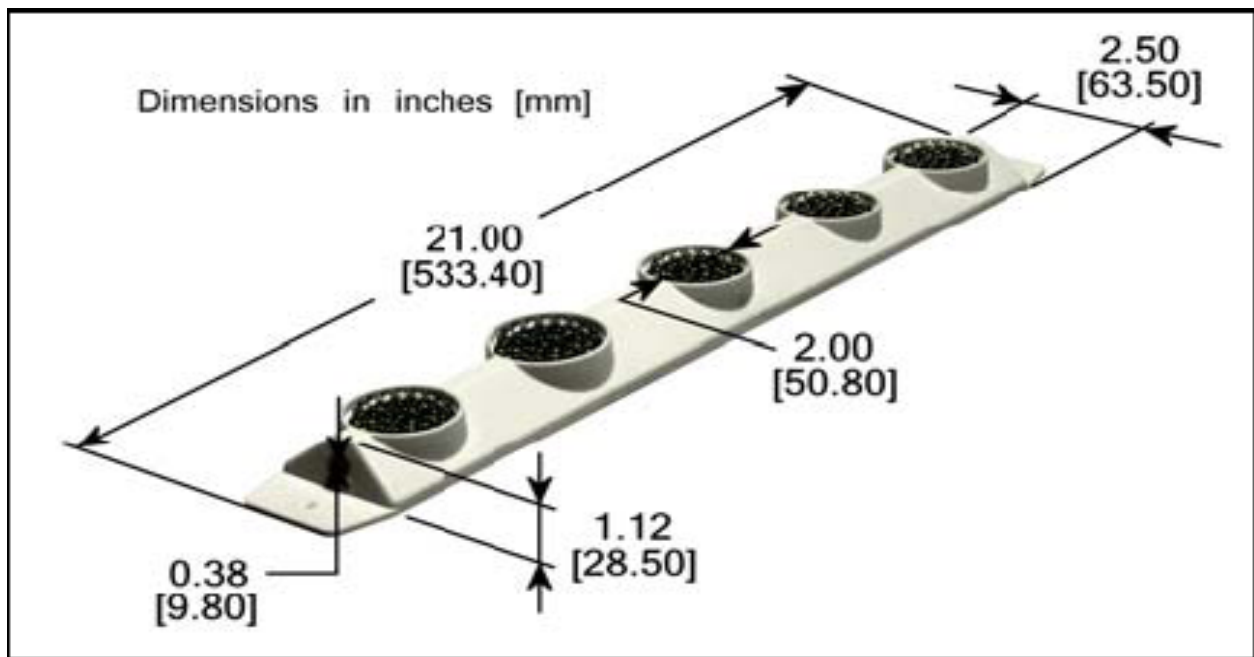


Figure 7: LED Five-array Grow-bar.

To cover large areas grow bars can be mounted onto frames to provide even lighting over a square area up to approximately 1.5m by 1.5m. The mounting arrangement is shown in figure 8. The distribution of light under this mounting arrangement is given in figure 9, the intensities on this light contour map are for the single array bars (LGM1), the intensities for the five array bars are claimed to be four times these intensities.

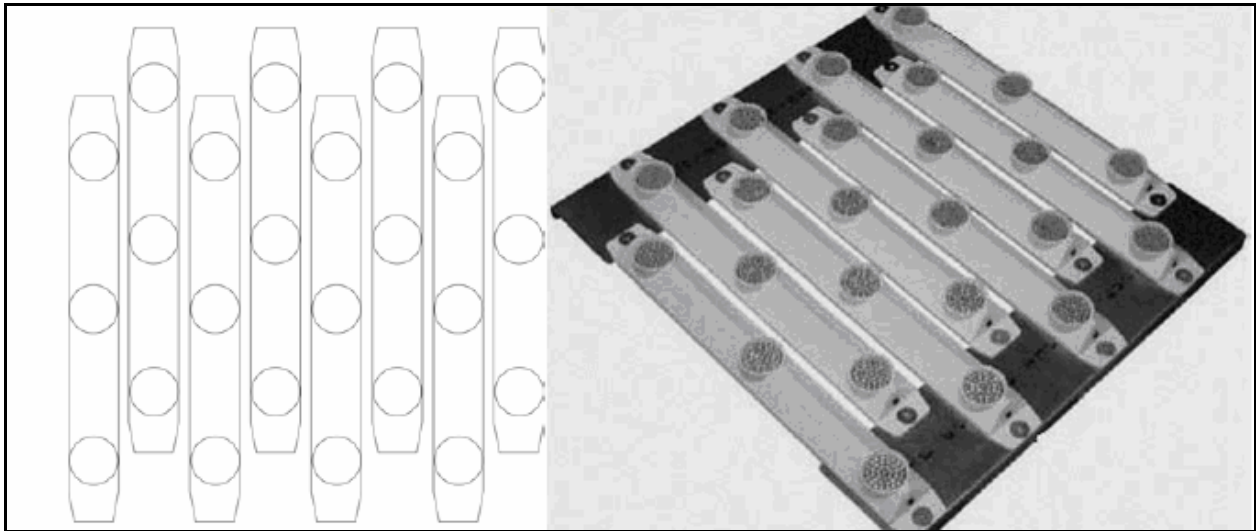


Figure 8: LED grow-bar mounting system from Growmaster Global (note three-array bars shown).

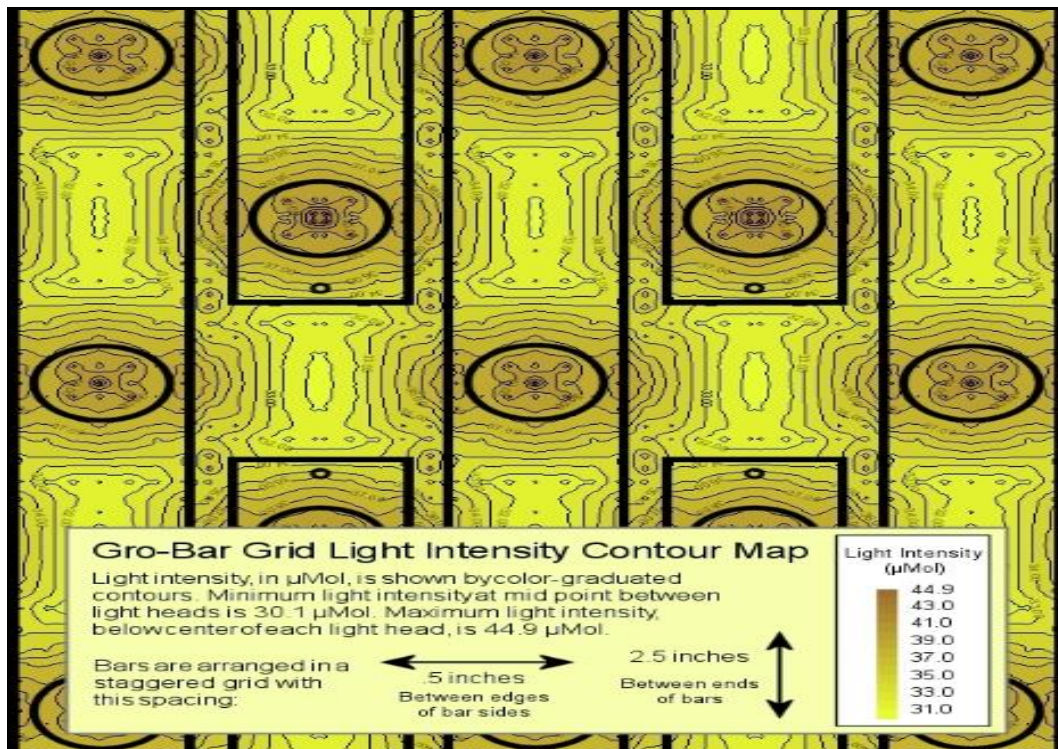


Figure 9: Light intensities produced by mounted single array grow bars.

Table 1 provides an estimated average light intensity under the light contour map (single array system) given in figure 9. Using the manufactures claim that four times the light intensity occurs under the five-array system it is estimated that around 150 μMol of photosynthetically available radiation (PAR) would be available. The distinction between PAR and light intensity is important here, as although HID bulbs produce more light intensity (μMol) only a fraction is PAR. For the LED system all of the light produced is PAR. The mounting frame is 558 mm x 558 mm, with eight five-array bars the light produced will cover an area from 914 mm x 914 mm, up to 1524 mm x 1524 mm sufficient PAR intensity for horticultural use.

Table 1: Light intensity from LED lighting

	Single Array Bars	Five Array Bars (estimated)
Min μMol	30.4	121.6
Max μMol	44.9	179.6
Average μMol	37.65	150.6

An estimation of lighting fixture positions for the hydroponics facility at Scott Base is given in figure 10. These positions are based on a maximum illumination area of 1500 mm x 1500 mm per mounting unit (Cardinale 2007). The dimensions of the hydroponics are based on the internal dimensions of standard 20-foot shipping crates taken from crate supplier Addis containers (ADDIS 2007).

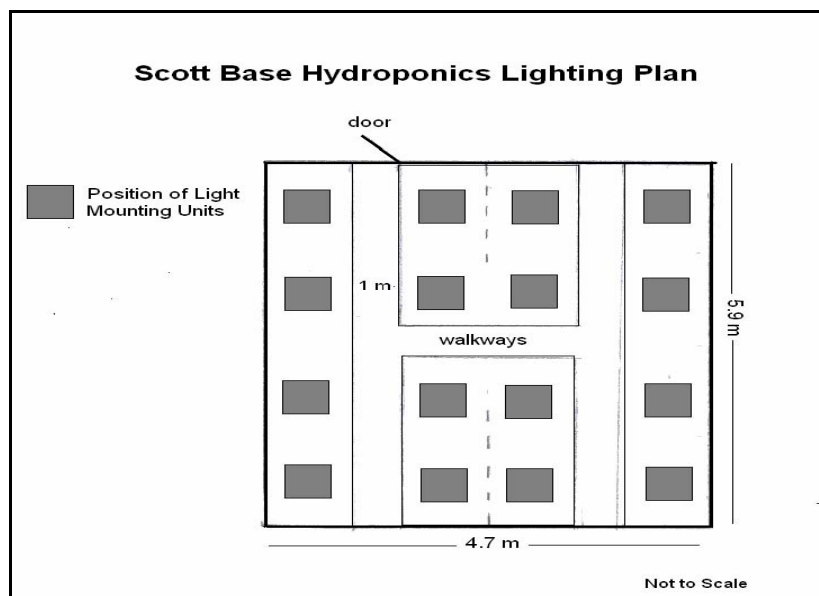


Figure 10: Proposed lighting layout for hydroponics facility at Scott Base.

The energy usage of LED lighting arrangement is around 1.1 kW. A rough estimation of the lighting that could be seen in the facility during a visit to the base put the current lighting power usage at 5 to 6 kW. If this estimation is accurate the LED lighting system would then represent a significant energy saving.

Table 2: Cost associated with LED lighting system.

Number of Five-Array Mounting Units	16
Number of Grow Bars Per Mounting Unit	8
Total Amount of Five-array grow bars	128
Cost per five-array Grow Bar (US \$)	\$260.00
Cost per Mounting Unit (US \$)	\$55.00
Total Cost (US \$)	\$34,160.00
Power Per Five-array Grow Bar (watts)	9
Total Power For hydroponic Lighting (kW)	1.152
Hours Lighting / Day	16
Power Usage / Day	18.432
Unit Cost Power (\$ / kWh) (Brookman 2007)	\$0.23
Running Cost / Day (NZ \$)	\$4.24
Running Cost / Nine Month Winter (NZ \$)	\$1,144.63

It will be necessary to install some of the light mounting units in a manner that the hanging height may be adjusted. This will involve manufacturing rails to raise and lower the lighting, adding additional cost to the project. The requirement to adjust the height is to the focus the light emitted from the array on to the crop. As taller crops such tomatoes and capsicums grow, the lights must be raised to give growing room and keep light levels constant. For shorted crops such as lettuce, spinach, herbs and strawberries, this adjustment is not required, as the lower crop does not affect the light focusing. The manufacturers recommendation is that the light array be suspended 18 to 28 inches above the plants (Cardinale 2007).

7.2 Reuse of Effluent

Currently the hydroponic system at Scott Base uses drinking quality water produced by the reverse osmosis plant. Reverse osmosis (RO) is the process of pushing a solution through a filter that traps the solute on one side and allows the pure solvent to pass through to the other side. When producing fresh water from seawater the solute is sea salt and the solvent is fresh water. At Scott Base reverse osmosis is used to provide for all fresh water requirements. RO is an energy intensive process, at Scott Base the energy required to produce fresh water is around 31.4 kilojoules per litre, excluding heating and delivery pumping (Brookman 2007).

Table 1 provides a brief estimation for energy associated with the production of fresh water for Scott Base. Assumptions are made regarding the operating hours of the seawater pump. Figures for daily water production, energy for RO process, power requirements for seawater pump and temperatures within process were received from Peter Brookman of Antarctica New Zealand. The final cost estimate for fresh water production based on a unit price of 23.00 cents per kWh is around \$44 per day.

Table 3: Estimated power consumption of total fresh water production at Scott Base.

water used per day (l)	6900
energy to produce by reverse osmosis (kj / l)	31.4
energy per day (kj)	216660
power requirement (RO process) kWh	60.18
sea water pump power (kW)	3
sea water pump hours of operation (estimated)	12
sea water pump power requirement (kWh)	36
E = 4.187(ΔT)(Mass Water)	Energy to heat water
ΔT= (-2° C – 10°C) = 12 °C	Change in temperature
Mass Water = 6900 kg per day	Mass of water per day
water pre heating energy (kj)	346683.6
water pre heating power (kWh)	96.30
Total Water Production Power (KWh)	192.48
Power Cost (\$ / kWh)	0.23
Total Water Cost (\$ / day)	44.27

This is one area where significant energy saving could be potentially made, if water recycling processes were implemented. One possible reuse of water is to use treated wastewater for the irrigation of the hydroponic crops. Although there are health concerns with using wastewater for agriculture, Antarctica New Zealand claims that a high level of treatment is achieved within the treatment plant. The water quality of the effluent leaving the base is claimed to be of “swimming pool quality”. Beyond this statement on the base tour, no information has been available to confirm effluent quality. Some major wastewater effluent parameters that would be required are summarised in table 4. Although no figures are available regarding the water usage of the hydroponics facility at Scott Base, the small amount of water used is unlikely to influence the overall cost of water production.

Table 4: Typical wastewater parameters.

Parameter	Description
Biological oxygen demand (BOD₅)	An indirect measure of the amount of organic material within the waste. Organic material is metabolised by heterotrophic bacteria, this consumes dissolved oxygen in the water. Reported in g / m ³ or mg / L
Total suspended solids (TS)	Suspended solids that are organic and inorganic in nature. Reported in g / m ³ or mg / L
Faecal coliform	Typical concentration of pathogens within the treated wastewater. Reported in MPN (most probable number) or number per volume.
Total nitrogen (TKN)	Nitrogen is a plant nutrient that can have adverse effects on the environment, especially in coastal areas where excess nitrogen stimulates the process known as eutrophication. Reported in g / m ³ or mg / L
Phosphorus (P)	Nutrient that can cause algal growth leading to eutrophication of coastal and fresh water environments. Reported in g / m ³ or mg / L
Metals	Common heavy metal pollutants are arsenic, cadmium, chromium, copper, nickel, lead and mercury. Reported in g / m ³ or mg / L

Nutrient concentrations within wastewater can be utilised by plants, although they are generally insufficient to be used a hydroponic nutrient solution alone (Ross 1998). However, the use of the nutrient rich wastewater effluent can reduce the amount of chemical fertilizer required within the nutrient solution. In the absence of information regarding the effluent standards of Scott Base, no recommendations are made to reuse this waste stream.

8 Bio Security

The biological invasion of non-native species is one of the greatest threats to biodiversity throughout the world (Poorter et al. 2007). Invasive species can quickly move into fragile ecosystems, eliminate competition and create a new structure with no resemblance to the former state of the environment. Many sub-Antarctic islands have already experienced severe ecosystem modification following the human and self-introduction of invasive species of plants and animals (Poorter et al. 2007). So far, the harsh and inhospitable conditions of the Antarctic continent have kept it free of invading alien species, with the exception of parts of the Antarctic Peninsula. However, it may only be a matter of time before the climatic conditions on the continent change sufficiently to allow for alien colonisation on the continent. Nations involved in the Antarctic treaty system realised the danger of non-native species as early as 1964 with the realisation of the Agreed Measures on Conservation, then subsequently in 1991 with the Protocol on Environmental Protection (Poorter et al. 2007). However, both of these sections of the Antarctic Treaty System fail to look beyond intentional importation of alien species into Antarctica. Perhaps the greatest threat to Antarctic ecosystems is the colonisation by alien species that are not anticipated.

8.1 Hydroponics and Biosecurity

When the hydroponics facility was decommissioned in 2004, the main reason cited was the bio-security risk, followed by the energy cost associated with the day-to-day running of the facility. Antarctica New Zealand had the best of intentions in limiting the ability of potentially invading organisms establishing at Scott Base (albeit in a heated moist greenhouse that does not resemble the local environs at all). However, what this knee jerk reaction fails to comprehend is that the two-time infestation is merely an indicator that bio-security procedures within the organisation are currently ineffective. Closing the hydroponics facility only eliminates the symptom, making the problem harder to detect. In many ways, the presence of a controlled environment similar to the New Zealand climate, such as the hydroponics facility, acts as an indicator to prove that bio-security procedures work or fall short.

The major control method used to destroy the springtail infestations of 2002 and 2004 was to rapidly drop the temperature and dry out the facility. To paraphrase the springtails were exposed to the outdoors, indicating that they were never likely to colonise the soils of Ross Island. This is not to say that all species that may venture to Scott Base will be so frail. Nevertheless, why not use a harmless (Townsend 1994) biological indicator such as “greenhouse bugs” to detect a biological problem. The problem is not with the hydroponics greenhouse, or with the kitchen staff entering the hydroponics greenhouse after handling New Zealand grown produce, the problem is with the lack of biological boarder control in Antarctic operations.

8.2 Invasion Vectors

Invading species must follow a route between one area and another, this route is generally defined as the pathway or vector (Fortune 2006). Throughout the world organisms follow a whole host of pathways to move from one colony and form a new colony. These pathways may include parasitic transport with human transit and cargo on land, in the air or by sea (Fortune 2006). However, some invasive organisms are equally likely to take advantage bird migration, marine and land animal movements and weather phenomenon. Although globally the complexity of invasion vectors may prevent accurate prediction and prevention of species invasion, in New Zealand’s Antarctic operations the vectors are very clearly defined by the route to the Ross Sea Region.

8.3 Vectors to Scott Base (New Zealand Operations)

The vectors between New Zealand and Scott Base are simple to define (Fortune 2006). Firstly, air cargo that arrives at Scott Base comes via USAF or RNZAF transport aircraft. These aircraft and their cargo arrive directly from Christchurch International Airport. The second vector is the shipping route; freight comes from Antarctica New Zealand’s site in Christchurch via Lyttelton Port of Christchurch (LPC). The sea freight is then handled at McMurdo station prior to delivery at Scott Base (Fortune 2006).

Within both of these vectors accidental and deliberate introduction of undesirable invasive species can occur. People can carry seeds and insect with their luggage, in their clothing or on their person. Freight on aircraft and onboard ships can harbour seeds, insects and even animals within the cargo itself as well as within the packaging material.

Relating to the springtail infestation of the hydroponics unit at Scott Base, the most likely vector is the fresh produce “freshies” that arrive twice weekly during the summer season. Pallets of fresh produce arrive at Antarctic New Zealand in Christchurch on the day of, or the day before a flight to Antarctica. The pallets are visually inspected to ensure they are clean, and two times per year MAF conducts an intensive inspection (Fortune 2006).

A University of Canterbury Masters project in 2006 investigated the level of contamination of the fresh produce destined for Scott Base. This investigation identified that the fresh produce and packing material were contaminated with soil, insects and spiders. The bottom of the wooden pallets were contaminated with dirt, and debris (Fortune 2006). Within the fresh produce layered vegetables such as cabbage and crowning lettuce appeared to be the most contaminated. In between the layers of leaves dirt, insects and spiders were present (Fortune 2006). This material is delivered directly to Scott Base and handled by the kitchen staff, who also harvest crops from the hydroponics facility.

Other vectors suggested by Antarctica New Zealand include seed packets from New Zealand. This seems unlikely as seed are generally marketed in sealed airtight foil packages, unless buying local organic seed varieties. The growing medium (vermiculite) was also suggested as a possible contamination vector. This is also very unlikely as the product is sold as a sterile growing medium. The production of vermiculite involves immense heat that would kill any biota present in the raw product.

9 Recommendations

This investigation has identified some actions that could be taken to reduce energy consumption in the hydroponics facility at Scott Base. The most notable of these is the upgrading of the conventional high intensity discharge and fluorescent lighting. The proposed upgrade to LED (light emitting diode) arrays would reduce the total lighting load to around 1.1 kW. This upgrade is not without its drawbacks, firstly the capital expenditure of around \$35,000 US to purchase the hardware, and then the labour required to install the lighting and modify the existing facility at Scott Base. For these reasons, it is unlikely that Antarctica New Zealand would initiate the upgrade, as they seem to regard hydroponics as a hobby facility rather than a legitimate food production device.

As far as biosecurity and Scott Base hydroponics, it would seem that Antarctica New Zealand is more concerned with signs that biosecurity procedures are ineffective than the fact that they are ineffective. If anything, the harmless infestation of an artificial habitat that vaguely resembles the New Zealand climate is a good tool to gauge the effectiveness of procedures in place that are intended to prevent New Zealand species reaching Ross Island. For this reason, the recommendation of this report is to reinstate the hydroponics facility without quarantine measures. The biological monitoring of the facility can then act as the litmus test to indicate the effectiveness of other needed biosecurity improvements.

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